

INNOVATION, RENT EXTRACTION, AND INTEGRATION IN SYSTEMS MARKETS

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Abstract: We consider innovation incentives in markets where final goods comprise two strictly complementary components, one of which is monopolized. We focus on the case in which the complementary component is competitively supplied, and in which innovation is important. We explore ways in which the monopoly may have incentives to confiscate efficiency rents in the competitive sector, thus weakening or destroying incentives for independent innovation. We discuss how these problems are affected if the monopolist integrates into the competitive sector.

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I. INTRODUCTION

Many high-technology markets, including the computer and communications industries, have the following characteristics: A number of strongly complementary components are used together in a system to provide consumer benefits, and some or all components are subject to significant technological progress as the result of suppliers' investments in R&D. An important issue for business strategy and public policy is how monopoly power in the provision of one component affects competition—particularly R&D competition—in the supply of complementary components.

We study this problem in the following setting. Components A and B are valuable only when used together. There is a single producer of A labeled firm M , which may or may not also produce B . There is also at least one independent supplier of component B . We examine two important questions. One, how does market power in the supply of A affect competition in the supply of B ? Two, how does integration by M into the supply of B affect the equilibrium outcome? The latter question is of interest in part because independent suppliers often complain of being “dependent on a competitor” when they face an integrated rival and may seek public policy intervention to protect them.

A familiar intuition asserts that when there is only one producer of component B , which we label firm N , integration through a merger of M and N would efficiently increase the incentives for each firm to innovate by internalizing what are otherwise positive external effects on one another. It has long been recognized (and usually attributed to Cournot (1838)), that integration may improve pricing incentives. In the Appendix, we identify conditions under which this result can be extended to innovation

incentives.² We show by example, however, that there are cases in which this intuition fails; integration can inefficiently reduce incentives to innovate when consumers differ in their valuations of the innovation. More important, the intuition does not carry over to the widespread market structure in which there are multiple suppliers of component B .³ In this case, when M enters the B market, it competes with independent B firms.⁴

Whenever there are independent suppliers of B , firm M has incentives to “squeeze” these firms: that is, to take actions that induce the independents to offer consumers as much surplus as possible in the B market.⁵ Firm M has incentives to engage in such squeezes because it can then extract that surplus in the A market. To some extent, this rent extraction generates incentives for firm M to promote efficiency in the B market. As we explore below, however, firm M ’s desire and ability to extract rents from independent suppliers *after* they have conducted their R&D may inefficiently reduce these suppliers’ innovation incentives, perhaps to the overall detriment of firm M .⁶

² A second difference is that we consider sequential, rather than simultaneous, pricing to make the results comparable to the rest of our analysis.

³ For example, Microsoft supplies operating systems (OS), and Microsoft and independent software vendors supply applications software that works with Microsoft’s OS. Similarly, Bell Atlantic supplies “access” that lets telephone subscribers make long-distance calls, and the non-access portions of those calls are supplied by a variety of long-distance phone companies, including Bell Atlantic. In this latter example, M ’s supply of A is largely controlled by regulation. The analysis of the unregulated case is important for fully understanding regulated markets, however.

⁴ Economides and Salop (1992) examine extension of the Cournot intuition to the price effects of various patterns of integration when there are multiple suppliers of each component in a model in which suppliers do not make entry or investment decisions.

⁵ We use the term “squeeze” without suggesting that the behavior is predatory or exclusionary.

⁶ This is an important difference between our model and DeGraba (1999). In a model without R&D investments, he establishes conditions under which firm M may produce component B in order to engage in an efficient price squeeze of independent suppliers.

These problems arise whether or not M is integrated into the development and production of B . However, integration into B often can strengthen firm M 's ability to force an independent producer of B to charge a lower price than it otherwise would. In a *price squeeze*, firm M strategically sets the prices of components A or B to induce independent suppliers of B to lower the prices of their variants. If firm M sets the price of component A before independent firms set the prices of their B variants, firm M may raise the price of component A to put pressure on the suppliers of complementary components. If it is integrated, firm M has an additional mechanism for engaging in a price squeeze: the firm can set the price its variant of B lower than would a stand-alone supplier in order to put direct competitive pressures on independent suppliers. Similarly, in an *investment squeeze*, an integrated firm M has strategic incentives to invest in improving its variant of component B in order to drive the leading independent supplier of B to price its (still better) product lower than it otherwise would. Note that under both a price squeeze and an investment squeeze, firm M does not engage in the squeeze to earn greater profits from the sale of its own variant of B ; instead, it lets the more efficient supplier of component B make sales and takes its profits in the market for component A .

An *exclusionary squeeze* provides a somewhat different mechanism. Under this type of squeeze, firm M demands a low price for an independently supplied component B as a *quid pro quo* for granting access. Again, firm M engages in the squeeze to increase the surplus available for extraction in the A market, not to promote sales of its variant of B .⁷ Although exclusion of rivals could increase M 's profits in the B market, any such

⁷ Thus, our analysis differs from traditional tying or exclusion stories in which the monopolist aims to weaken rivals. For classic analyses of the price effects of tying and exclusion, see Bowman (1957) and Whinston (1990). Like us, Choi (1998) considers the

profits would come at the loss of at least equal profits in the A market. Thus, our model incorporates the “one monopoly rent theorem.” Despite this, we find that integration by M can create dynamic efficiency problems.

Actual and threatened exclusion are in principle available to M as strategies whether or not it is integrated into B . However, if it were illegal for M to engage in exclusion, integration could arguably make it harder to verify that firm M had carried out its threat. If M did not integrate, firm M would have to treat the independent suppliers asymmetrically because it would have to exempt at least one from exclusion. If M integrated, firm M could most likely make colorable arguments about the need for confidentiality and protection of intellectual property rights that would allow the firm to close the A - B interface to all independent suppliers.

The paper is organized as follows. The next section lays out a simple model. Section III analyzes squeezing through investment strategies and Section IV examines threats of exclusion as a means of squeezing independent suppliers. Section V relaxes some assumptions of the baseline model in order to consider markets in which firm M may engage in price squeezes. Section VI discusses the effects of relaxing a restrictive demand assumption made in our baseline model. Section VII briefly examines firm M 's incentives to invest in improving component A . The paper closes with a conclusion.

effects on innovation of firm M 's production of two goods. The monopolist in his model, however, ties two *independent* goods in order to induce rival suppliers of the tied good to compete less vigorously in making R&D investments. Not only are the two goods in our analysis not independent, but (because of that) our monopolist never wishes to induce rivals to innovate less vigorously—when that happens in our model, it is an unwanted side effect of M 's behavior.

II. THE BASELINE MODEL

For most of the paper, we analyze the following three-stage game.

Entry Stage: In the first stage, firm M and independent suppliers decide whether to enter the market for component B . We discuss alternative orders of decision making by firm M and the independent suppliers below. The firms' entry decisions then become common knowledge.

R&D Stage: Those firms that are active in the market for B then simultaneously invest in improving their quality levels (or lowering their costs). This investment gives rise to a distribution function for firm i 's product quality, q_i . We assume that an increase in R&D investment leads to a first-degree stochastic improvement in the distribution of product quality. We also assume the quality improvement enjoyed by one firm is independent of the R&D investments of other firms. We are thus ruling out both patent races and the possibility of spillovers across R&D programs while they are under way.⁸ Below, we consider the possibilities of licensing and ex post imitation. We also assume that each firm, including M if integrated, has the same R&D technology: we thus ignore technological efficiencies of integration.

Pricing Stage: At the start of this final stage, the R&D outcomes—the firms' product qualities—are common knowledge. Suppliers of B simultaneously and non-cooperatively set prices for their components: let p_i denote the price chosen by firm i . Firm M observes the prices and qualities of all variants of component B and sets the price of component A . We assume for simplicity that the marginal costs of production are zero

⁸ This assumption is an important difference from Choi (1996). In his model, the firms compete in a patent race (bidding war). He demonstrates that firm M may force consumers to purchase both components from it in order to weaken its rivals in that race.

for component A and c for all variants of B . Throughout most of the exposition, we subsume c in the demand curve and take $c = 0$ as a normalization.

Once all prices have been set, consumers decide whether to buy a system and, if there are multiple suppliers of component B , which one to patronize. There is a unit mass of consumers, each of whom buys either 0 or 1 system. A type- θ consumer has a reservation price of $\theta + q$ for a system that combines one unit of A with one unit of good B having quality q : components A and B must be used in fixed proportions (normalized as 1-to-1) to generate benefits.⁹ $G(p)$ denotes the number of consumers for whom $\theta \geq p$. We assume there exists a finite price v such that $G(p) = 0$ for all $p > v$.¹⁰ In the baseline model, we also assume demand is inelastic:

$$G(p) = \begin{cases} 0 & \text{if } p > v \\ 1 & \text{if } p \leq v. \end{cases}$$

Thus, each consumer is willing to pay $v + q$ for a system that incorporates quality q of B .

III. INVESTMENT SQUEEZES

We begin by analyzing the game's equilibrium and the incentives to invest in R&D. To find a subgame-perfect equilibrium, we solve the game by working backward in time.

⁹ Given the assumption that all consumers value quality equally, an increase in quality is equivalent to a decrease in cost. In the Appendix, we briefly relax the assumption that all consumers value quality equally.

¹⁰ In addition to being realistic, the assumption of a finite choke price rules out certain mixed strategy equilibria that might otherwise exist in which a firm that has the lowest quality (or highest cost) makes equilibrium sales at a price strictly above cost.

A. Analysis of the Pricing Stage

Suppose B -firm i has quality q_i and sets price p_i . Define firm i 's quasi-surplus as the surplus that a consumer would get from buying B from firm i if he could then get A for free: $s_i = v + q_i - p_i$. Let the maximum quasi-surplus offered by any seller of B (including M if integrated) be $s^{**} > 0$. Given this quasi-surplus level, firm M sets the price of A equal to s^{**} and sells to all consumers, extracting all consumer surplus and making profits of s^{**} in the A market.

If M has integrated into B and actually makes sales of B , with quality q , price p , and resulting quasi-surplus of $s = v + q - p$, then its product-market profits are equal to $p - c$ in the B market and s in the A market, for a total of $v + q - c$. Note that this is independent of p . If, on the other hand, an independent sells B , providing quasi-surplus s , and firm M supplies only A , then M 's total profit is equal to s . Therefore, if s^* is the highest quasi-surplus offered by one or more independent(s), then firm M would like to sell its variant of B if and only if $v + q - c > s^*$. Any price less than or equal to $v + q - s^*$ allows firm M to make sales and earn $v + q - c$ from the sale of A and B . But setting $p = c$ is the unique strategy that maximizes profits for every possible value of s^* . Thus, firm M 's pricing its variant of B at cost is a weakly dominant strategy and is the only one that satisfies a trembling-hand perfection requirement.

Now consider pricing by independents. No independent firm will price below cost to win sales, but each is willing to go as low as cost to win. Unlike firm M , however, an independent wants to charge the most it can (given inelastic demand) for its product. Thus, each independent supplier sets its price at cost if it is not the highest-quality producer, and at cost plus the difference between its quality and the second-best quality if its variant does have the highest quality. This outcome is the standard Bertrand outcome.

The independent suppliers' pricing strategies (as functions of the vector of all quality levels) are thus unaffected by whether or not one of the B -sellers is an integrated firm M . Moreover, the producer of the highest quality good B always makes the sales, whether or not firm M integrates. Because demand is inelastic, this latter fact implies that *conditional on R&D outcomes*, the market outcome is ex post efficient with or without integration by the monopolist.

B. Analysis of the R&D Stage

Now, consider incentives to conduct R&D. If an independent supplier has the highest-quality B , it earns a per-unit margin equal to the difference between its quality and the second-highest quality. This margin is also the social contribution of that highest-quality B -firm. Other B -firms earn no revenues, and their ex post social contributions are zero. Therefore, each independent B -firm has efficient incentives to improve its variant, given the joint probability distribution of the qualities of other suppliers. This is a familiar result in the context of an isolated market.

If M is integrated into B , its total profits from the sale of A and B are equal to the maximum of (a) its own quasi-surplus (given that its variant of B is priced at cost) and (b) the highest quasi-surplus offered by an independent. From our analysis of pricing by independents, we know that the latter will equal the quasi-surplus offered by the *second-highest* quality level, priced at cost. Thus, when firm M 's variant of component B is not the best, an improvement in the *second-best* B causes the *best* B to price lower and offer more quasi-surplus. This increase in quasi-surplus allows firm M to price A higher. Although these price changes have no direct efficiency effects, they transfer rents from an independent producer of the best B to firm M . By investing in R&D, firm M can squeeze

ex post quasi-rents from the B -winner: M 's profits increase if it improves its variant of B to a level between the two highest levels of the independent suppliers' variants of B . Consequently, an integrated firm M has strictly excessive incentives to improve its B product if there is positive probability that it will end up alone in second place overall.¹¹

Summarizing this discussion,

Proposition 1. *In the baseline model: (i) conditional on the R&D levels of all other firms, an independent supplier does the socially efficient amount of R&D whether or not M is integrated; and (ii) if M integrates into B , it has excessive incentives to innovate conditional on the R&D levels of the independent firms.*

The Cournot intuition points out that, through firm M 's residual claim on complementary good A , integration may internalize what would otherwise be *real* externalities from leading-edge innovation in B . The discussion above, however, points out that an integrated firm M may also capture a *pecuniary* externality from catch-up innovation in B . When there is just one B -firm, the catch-up effect does not arise and the pecuniary effect vanishes. With inelastic demand and multiple B -firms, however, the real externality vanishes and the pecuniary externality survives.

We can say more about the nature of equilibrium if we put somewhat more structure on the model. Suppose there are only two possible outcomes of an R&D project, *success* and *failure*. Normalize failure as $q = 0$ and success as $q = 1$. In order to have a p probability of succeeding, a firm must invest $I(p)$, where $I(0) = 0 = I'(0)$ and

¹¹ Such a firm might adopt the slogan, "We're number two (because) we try harder."

$I''(0) > 0$. Under these conditions, firm M conducts more R&D than any other firm in equilibrium.¹²

C. Analysis of the Entry Stage

Now consider incentives for entry. We saw above that equilibrium in the absence of integration maximizes expected total surplus conditional on the number of firms—thus integration cannot be strictly superior when the total number of B suppliers is unaffected by M 's integration decision.¹³ The following example shows that profitable integration can lead to a strict fall in total surplus.

Example. With or without integration, there are two producers of B —either there are two independents, or there is firm M plus one independent, N . The R&D cost function satisfies the conditions of the success-failure model, with the particular functional form $I(p) = p^2/(2k)$, where $0 < k < 1$.

If both suppliers of B are independent, each invests $p = k/(1+k)$ and earns expected profit (net of R&D costs) of $k/[2(1+k)^2]$. If unintegrated, M earns expected profit of $p^2 = [k/(1+k)]^2$. Expected total surplus is equal to $k/(1+k)$, which is the maximum possible given the technology and the number of innovators.

If M integrates with one of the B -firms, the integrated firm sets $p = k$ and earns expected profit of $k/2$, while the remaining independent B -firm sets $p = k(1-k)$. Firm M

¹² This is proved formally in Lemma A.3 of the Appendix.

¹³ In this case, firm M 's decision to integrate into B could be thought of as an acquisition of one of the fixed set of B suppliers. Although we do not model the bargaining game, note that firm M might be in a favorable bargaining position because a B -supplier that did not merge would face the prospect of being squeezed by an integrated rival.

does more R&D than does either independent firm in the non-integration equilibrium, and firm N does less. Expected welfare is $k(1 - k)^2 + k^2/2 < k/(1+k)$.

It follows from these and simple further calculations that integration is privately profitable (*i.e.*, the joint profits of the merging firms rises) and socially inefficient. An integrated firm inefficiently conducts more R&D because it benefits from a quality squeeze (pecuniary externality) and thus values innovating even if the other firm has innovated as well. The remaining independent N efficiently reduces its R&D in response to the inefficient increase in its rival's incentives.

Summarizing this discussion,

Proposition 2. *In the baseline model, if the total number of B suppliers is unaffected by M 's integration decision, then M has weakly excessive incentives to integrate and profitable integration can strictly reduce total surplus.*

Now suppose there is free entry into B after M has committed either to integration or non-integration. If firm M does not integrate, independent suppliers have excessive incentives to enter the market for component B . To see this, let $W(I_1, I_2, \dots, I_{n+1})$ denote the resulting level of expected total surplus when firms 1 through $n+1$ undertake R&D investments $(I_1, I_2, \dots, I_{n+1})$. Let $(I_1^*, I_2^*, \dots, I_n^*, 0)$ denote the vector of R&D levels that maximizes welfare subject to the constraint that $I_{n+1} = 0$. As noted above, $(I_1^*, I_2^*, \dots, I_n^*, 0)$ is a Nash equilibrium in the R&D stage given Bertrand product-market competition and inelastic demand, and given that firm $n+1$ is "out." Now, suppose that independent firm $n+1$ enters the market for B in the entry stage. Let $(I_1^{**}, I_2^{**}, \dots, I_{n+1}^{**})$ denote the resulting equilibrium R&D levels. Firm $n+1$'s expected profits are $W(I_1^{**}, I_2^{**}, \dots, I_{n+1}^{**}) - W(I_1^{**}, I_2^{**}, \dots, I_n^{**}, 0)$, its social contribution taking as given

all others' actions. But the true social contribution of its entry (taking account of others' reactions to that entry) is $W(I_1^{**}, I_2^{**}, \dots, I_{n+1}^{**}) - W(I_1^*, I_2^*, \dots, I_n^*, 0)$. By definition, $W(I_1^{**}, I_2^{**}, \dots, I_n^{**}, 0) \leq W(I_1^*, I_2^*, \dots, I_n^*, 0)$. Therefore, firm $n+1$ has weakly excessive incentives to enter. These incentives will (generically) be strictly excessive when entry induces rival suppliers to change their equilibrium R&D levels.

Despite the distortion in the independent suppliers' entry incentives, firm M has approximately correct incentives. Ignoring integer constraints, independent suppliers of B make zero expected profits given M 's integration decision. Because consumers also earn zero surplus in equilibrium, firm M internalizes all efficiency effects of its integration decision and thus has efficient incentives to integrate. Thus,

Proposition 3. *In the baseline model, suppose there is free entry into B after M has committed to integrating or not. Independent suppliers have excessive incentives to enter the market for component B if firm M does not integrate, and—ignoring integer constraints—firm M has efficient incentives to integrate.*

This is a strong internalization claim. Importantly, even in this special case the logic does not carry over to decisions, such as the level of R&D investment, made by firm M after independent suppliers have made their entry decisions. However, the same free-entry argument implies that M would like to commit to efficient choices on those dimensions.¹⁴ Our model implicitly assumes that contractual commitments of this sort would be prohibitively difficult to enforce.

¹⁴ Formally, consider decision, x , and suppose that, in the absence of commitment, firm M would choose a level of x that did not maximize surplus given previous choices and subsequent responses. Then some other level, x^* , would yield higher expected total surplus. If M could commit to x^* ex ante, its expected profits would rise given that

IV. EXCLUSIONARY SQUEEZES AND COOPERATION

Business executives often express concern that integration by a firm in M 's position will allow it to exercise its control over component A (and its interface with B) to disadvantage independent firms competing with M in the supply of B . Especially in high-technology contexts, where the interface between A and B may be rapidly changing and/or subject to intellectual property protection, firm M may well be *able* to control how effectively the independent rivals can compete. Consequently, an important issue is whether M has an *incentive* to help or hinder independent B firms.

In our baseline model, firm M never loses from independent innovation, and the firm strictly gains from it whenever such innovation strictly raises the quasi-surplus offered to consumers. The change in quasi-surplus depends, in part, on what forces drive the pricing of the winning variant of B . When the leading innovation is *non-drastic*, the leader offers the same quasi-surplus to consumers as does the second-best variant when the latter is priced at cost. When an innovation is *drastic*, the winning supplier prices B as if it had no competition from other suppliers of B .¹⁵ In the baseline model (with complete information and inelastic demand), innovations always are non-drastic. Therefore, firm M 's profits are an increasing function of the second-highest quality as

expected consumer surplus and expected profits of independent suppliers would remain equal to zero.

¹⁵ One issue is how to identify when an innovation for a single component in a system is drastic. Interpreting $-q$ as a cost, the standard condition for a cost-reducing innovation of a stand-alone product to be drastic can be applied when demand takes any of the following forms: $D(p) = \alpha + \beta p$, $D(p) = \alpha e^{\beta p}$, or $D(p) = \alpha p^{\beta}$, where α and β are constants. For this class of demand functions, a monopoly supplier facing demand D for component B alone would choose the same price as it would if it faced demand $x^*(p)$, where x^* was derived from systems demand D and firm M 's strategy for pricing component A conditional on the price of B . Proofs of these claims are provided in Lemmas A.1 and A.2 in the Appendix.

long as firm M is not offering the highest-quality variant (in which case M 's profits are independent of the second-highest quality).

We draw two lessons from these facts. First, especially to the extent that M cannot know whether it is helping a future runner-up who may pressure the leader, firm M has broad incentives to cooperate with independents, and no incentives to hinder them, whether or not firm M is integrated.¹⁶ Second, firm M may be able to take actions that tend to improve the second-highest quality while worsening overall efficiency (including perhaps worsening the highest quality). For instance, M might refuse to allow the winner access to A unless the winner licensed its innovation to other B -firms. However, with a fixed set of B firms, we have seen that zero spillovers maximize welfare in our baseline model. A small increase in spillovers thus would necessarily (at least weakly) reduce welfare by reducing investment incentives. But, by improving the expected quality of the second-best variant, a small increase in spillovers might increase M 's profits.

The obverse of cooperation is deliberate exclusion. In our model, there are three ways in which *threatening* exclusion could be profitable for firm M (although carrying out the threat is never profitable). First, firm M could demand side payments, or *access charges*, in return for granting access to the complement.¹⁷ Second, firm M could implement an *exclusionary squeeze*: firm M could insist that a supplier of component B commit to charging a low price, which would increase the profits firm M would enjoy

¹⁶ As we discuss below, when demand is responsive to price, an innovation can be drastic and firm M can strictly gain even when only the highest independent quality level increases. In this case, firm M has incentives to assist an independent innovator even if it has the highest quality variant of B .

¹⁷ But it is self-defeating to impose access charges that cause the winning B -firm's offer of quasi-surplus to decrease *pari passu* (or, worse, by more than the access charge).

from the sale of component *A*. Third, if the threats and commitments can be made prior to the conduct of R&D, firm *M* might use the threat of exclusion (or the promise to exclude others) as a means of increasing an independent supplier's R&D investment. In our model, there is no incentive for firm *M* to threaten or engage in exclusion, whether or not it has integrated, if the above options are not available.

Outside our model, we remind the reader of some possible reasons why firm *M* might wish to exclude an independently developed component *B*. First, when components *A* and *B* can be used in variable proportions to generate consumer benefits, firm *M* might be able to extract more surplus from buyers by excluding other component suppliers in order to create greater flexibility in its relative pricing of components *A* and *B*.¹⁸ Clearly, this motive does not apply when goods *A* and *B* are used in fixed proportions, as in our model. Second, we assumed that additional entry into the production of component *A* is impossible. If such entry were possible, firm *M* might wish to exclude based on fears that independent production of *B* could serve as a stepping stone into the *A*-market—so-called two-stage entry.^{19, 20}

V. PRICE SQUEEZES

Recall that a price squeeze occurs when firm *M* sets its prices so as to make an independent supplier of a superior variant of *B* set a lower price than it otherwise would.

¹⁸ This issue and the literature addressing it are discussed in Katz (1989). If consumers have imperfect foresight about service or spare parts pricing, this can also potentially create a motive to exclude suppliers of those complements.

¹⁹ For an analysis of how a firm can preserve its monopoly position through tying, see Carlton and Waldman (1998).

In the baseline model, there is no scope for firm M to engage in a price squeeze, whether or not it is integrated. In other settings, however, a price squeeze may be possible. In this section, we present two (separate) modifications of the product-market stage that allow firm M to engage in price squeezes. First, we let firm M act as a Stackelberg leader in pricing either A or B . Second, we examine what happens when the outcomes of R&D are not common knowledge at the time prices are chosen.

A. Price Leadership

Our baseline model assumes that firm M sets the price of A after any independent suppliers have set the price of B , and that if it integrates firm M sets the price of its variant of B simultaneously with other suppliers. In this part, we consider the effects of leadership by M in the pricing of either A or B .

First, suppose firm M sets the price of A before any firm sets the price of its B variant. In this case, M sets the price of A to just below v plus the highest of the B -qualities. The highest-quality B then makes all the sales of B and makes infinitesimal quasi-profits: M extracts all the quasi-profits through pricing A . The prospect of this squeeze destroys independent innovation in B . In this case, firm M 's integrating may be the only way to sustain innovation.²¹

²⁰ Even when two-stage entry is feasible or the components are not used in fixed proportions, firm M may not have incentives to exclude independent suppliers of B if it can levy a combination of fixed and per-unit access fees on those firms.

²¹ When quantity demanded is sensitive to price (*i.e.*, not perfectly inelastic), the winning B -firm's response to an increase in the price of A will not be perfect accommodation. Generically, firm M will suffer lost system sales if it raises the price of A to confiscate an independent supplier's ex post efficiency rents, and consequently those efficiency rents will not be fully destroyed.

Somewhat similar effects arise if firm M can act as a Stackelberg leader in the pricing of B . When it does not create the highest-quality B , M has an incentive to price its inferior product *below* cost so as to affect the pricing of the superior product. Specifically, suppose that the highest-quality variant of B has quality q , which would enable its independent supplier to offer quasi-surplus s^{**} if the product were priced at cost. Absent a price squeeze by M , the independent supplier would not price its winning product at cost, but would take an efficiency rent. However, suppose that M first sets its price of B below cost so as to offer quasi-surplus of nearly s^{**} . This independent supplier will have to respond by pricing its product just above cost. Firm M 's inferior variant of B makes no sales in this price squeeze, but transfers all of the independent suppliers quasi-rents to M 's complementary operations in A . Again, this pricing game (whose outcome is ex post optimal for M) inefficiently destroys all ex ante incentives for independent innovation by B . Thus, either M integrates and innovates alone, or M stays out of the market for component B and allows others to innovate. With inelastic demand, firm M has efficient incentives to innovate given that it is the sole innovator. However, it could nevertheless be socially and privately optimal to have multiple innovators, depending on the technology of innovation.

While the pricing games formally analyzed here are artificial, their implications are not. In the much more complex pricing games played in reality, independent suppliers of complements presumably react to the prices charged by integrated firms. Price-squeeze effects would then arise, although to a less extreme degree than in the extreme price-leadership games considered here.

B. Incomplete Information

We now explore a different mechanism by which a price squeeze may arise: independents respond to the *anticipation* of firm M 's setting a low price. To investigate this mechanism, we consider the following game of incomplete information. The suppliers of component B simultaneously set the prices of their variants before learning the quality levels of their rivals. That is, the suppliers of B simultaneously announce their prices and qualities.²² After these prices and qualities become common knowledge, firm M sets the price of component A . For simplicity, we assume R&D investment levels are private information at the time firms choose the prices of their variants of B .²³

Suppose that firm M is integrated into B . In the Appendix, we prove (generalizing the complete-information case):

Lemma 1. *It is a weakly dominant strategy for an integrated firm M to price its variant of B at cost. No other strategy satisfies the trembling-hand perfection criterion.*

Now, consider the independent suppliers of B . We say that firm i *hopes to be best at quality q* if, according to its subjective beliefs about other suppliers' quality levels, there is strictly positive probability that $q_j < q$ for all $j \neq i$.²⁴ Of course, in the complete-information case, firm i hopes to be best if and only if it actually has strictly the highest quality level. In the Appendix, we prove (generalizing the complete-information case):

²² Unless the rate of technological change is very high, it is somewhat artificial to assume that firms cannot adjust their prices after product qualities become common knowledge. We make this assumption to simplify our illustrative model

²³ We maintain this assumption in order to avoid the complications of pricing strategies that are contingent on rivals' investment levels.

²⁴ These beliefs are derived from the R&D production functions of the rival suppliers as well as firm i 's beliefs about its rivals' investment levels.

Lemma 2. *An independent supplier of component B: (i) never makes equilibrium sales at a price less than cost, and (ii) sets price strictly above cost for all quality realizations at which it hopes to be best.*

Intuitively, each independent prices strictly above cost so as to make profits should it be lucky enough to have the highest quality. It trades off this desire against the fact that it sacrifices profits if it misses selling because of its markup. In contrast, firm *M* suffers no such tradeoff because it can lower its price and make up its sacrificed *B*-profits one-for-one in *A*.

Now consider the ex post (*i.e.*, conditional on the set of realized quality levels) efficiency effects of integration. When firm *M* does not integrate, the independent firm with the highest-quality variant makes the sales in any pure-strategy symmetric Bayesian equilibrium. When *M* integrates, it prices at cost while its rivals price above cost. Thus, firm *M* always sells *B* when it is efficient for it to do so, and sometimes when it is inefficient. Consequently, with inelastic demand, integration lowers ex post efficiency:

Proposition 4. *Suppose quality levels are private information at the time suppliers set the prices of component B. In any pure-strategy, symmetric Bayesian equilibrium, the highest quality B-supplier efficiently makes all of the sales when M does not integrate.²⁵ When it integrates, firm M always makes equilibrium sales of component B if it has the highest quality and may make equilibrium sales of B when it is not the highest quality variant. With inelastic demand, integration lowers ex post efficiency.*

²⁵ Maskin and Riley (1996) prove that—conditional on all suppliers of *B* choosing identical R&D investment levels—the pricing stage-game in our model has a unique equilibrium when the density function for the distribution of product quality conditional on the level

This result stands in contrast to the baseline model with complete information in which integration had no effect on ex post efficiency.

Although it is not a price leader in the model under consideration, firm M may still execute an indirect price squeeze by integrating. When information is incomplete, the independent firms' Bayesian pricing strategies may respond to the knowledge that firm M has integrated and that, unlike an independent, it will price its component B at cost. One might expect this response to take the form of a lower price for any given quantity. In this case, firm M has a private incentive to integrate, because integration creates an indirect price squeeze and raises the surplus that can be extracted through the sales of A . Interestingly, however, in some cases independent suppliers will respond to firm M 's pricing at cost by charging *higher* prices than they would do if competing against another independent firm.²⁶ In these cases, the indirect pricing effect of integration reduces firm M 's profits.

Incompleteness of information also affects firm M 's incentives to cooperate with independent suppliers. In contrast to the complete information case, if information is incomplete, firm M always has strict incentives to help an independent supplier—even when firm M is integrated, there is only one independent firm (firm N), and innovation is non-drastic. The reason is that independent firm N cannot observe M 's quality level and thus N must price based on its subjective beliefs about M 's actions. A higher quality of firm N 's variant will induce the firm to offer a higher level of quasi-surplus. This higher level of quasi-surplus will increase firm M 's profits from the sale of component A .

of R&D investment is continuous and positive on a closed interval. They also show that the equilibrium comprises symmetric pure strategies.

VI. RESPONSIVE DEMAND

To this point, we have assumed that demand is perfectly inelastic up to a choke price. This assumption greatly simplifies the analysis, but does so at the cost of ruling out several types of efficiency effects. In this section, we consider the effects of less than perfectly inelastic demand, which we refer to as *responsive demand*. We continue to assume that the system components must be used in a 1-to-1 ratio.

In our baseline model, integration had no efficiency consequences through its effects on post-R&D behavior. With responsive demand, integration by firm M can give rise to efficiency effects in the pricing stage because firm M chooses the price of its variant of B taking into account the effects on the sales of systems. There is a direct effect because firm M prices its B variant at cost: If consumers buy that variant, the quantity is chosen more efficiently than if it were priced above cost by an independent.²⁶ As discussed in Section V above, in the incomplete information case, there may also be an indirect pricing effect of integration.

Analysis of the R&D stage is also affected if demand is responsive. In our baseline model, independent suppliers conduct the optimal amount of R&D conditional on the investments of other suppliers, while an integrated firm generally conducts socially excessive R&D, for the following reason. Each firm appropriates the full social benefits of innovation when it has the highest quality variant of B . There is no social value to improving the second-best variant, nor is there any value to an independent

²⁶ Example A.1 in the Appendix illustrates this possibility.

²⁷ Although there remains a monopoly stage in which firm M sets the price of A , with responsive demand the price remains lower (given the quality) if the quasi-surplus offered in good B is higher.

supplier. Through a squeeze, however, the integrated firm enjoys a private value from improving its variant when it is second best.

When demand responds to price, innovation that improves the second-best variant of B has social value—an increase in the quality of the second-best variant drives the price of the best variant closer to cost and thus improves allocative efficiency. Now, the independents' failure to perceive such a value can lead them to do too little R&D. Moreover, when the innovation is drastic, an innovator with the best variant may appropriate less than the full social value of the innovation, placing a wedge between the social and private incentives for all firms. Thus, conditional on the R&D investments of its rival, an independent B -supplier's investment incentives are biased downward.

In the case of firm M , there are biases in two directions, and firm M may have socially insufficient or excessive incentives to innovate conditional on the R&D levels of other suppliers when demand is not perfectly inelastic. As we saw above, with inelastic demand firm M has strictly excessive innovation incentives. This result can be extended to examples in which the quantity demanded responds to price. The following example is one in which firm M 's incentives are too low: Given fixed costs of production and the scale of demand, equilibrium entails a single supplier of B , and under integration it is M . Because demand responds to price, innovation leads to an increase in consumer surplus. Therefore, firm M has insufficient incentives to innovate when it is integrated.

Even when its incentives are biased downward from a social perspective, firm M has greater innovation incentives than its independent rivals in the following sense. Conditional on being first, the benefits to firm M are at least as large as they would be to an independent firm with the same realized quality. Conditional on being second, firm M

enjoys benefits from the squeeze placed on the independent supplier with the highest quality, while an independent supplier with the second-best variant would enjoy no benefits. There are no private benefits to any firm from being third or worse. It follows that there are no equilibria with symmetric R&D levels. To see why, suppose that all firms conducted I_0 of R&D investment and this level was a best response for each independent firm given the R&D investments of its rivals. By the arguments above, firm M would have incentives to conduct more than I_0 of R&D investment.²⁸

Turning to the integration decision itself, in our baseline model, we found that in some circumstances the monopolist had excessive incentives to integrate in order to engage in an investment squeeze. This possibility arises with responsive demand as well (by continuity). However, there may also be cases in which the monopolist's private integration incentives are less than the social incentives because some of the benefits of integration accrue to consumers.²⁹

Lastly, consider the effects of responsive demand on the monopolist's incentives to assist independent suppliers of component B . Under complete information, firm M has no incentive to help a sole independent supplier for any R&D function and demand structure such that innovation is non-drastic. For sufficiently large differences in quality, however, innovation will be drastic. In this case, a higher quality level by the leading supplier of B results in increased profits for firm M , creating incentives for cooperation.

²⁸ This point is established more rigorously in the Appendix.

²⁹ This case arises, for example, when the monopoly supplier of component A integrates with a firm that is the sole supplier of component B . While the monopolist enjoys gross benefits from integration, these private benefits are less than the change in total surplus, which includes the increase in consumer surplus (see the Appendix). Thus, if there are transactions costs of merging, the net private incentives may be negative even when the net social incentives are positive.

While consideration of responsive demand complicates the story, the basic plot survives: Integration can facilitate investment squeezes and (explicit and implicit) price squeezes that have divergent private and social benefits. On the other hand, the monopolist in our model (whether or not integrated into B) does not want to exclude independent suppliers of B , and typically has incentives to assist them.

VII. INNOVATION IN COMPONENT A

We now briefly consider firm M 's incentives to improve component A . To be precise, we examine the question within the context of the following game, but some generalization is possible. Suppliers of component B invest in R&D and the resulting quality levels become common knowledge. Firm M then invests in R&D to improve component A , and the resulting improvement becomes common knowledge. The suppliers of component B then simultaneously set the prices of their variants, after which firm M sets the price of A .

Let t denote the characteristic of component A that firm M attempts to improve through R&D investment. We assume that an increase in t corresponds to a quality increase that uniformly shifts demand upward or a cost decrease that uniformly shifts marginal cost downward. Let $\pi(t, p_A(t), p_B(t))$ denote firm M 's profits as a reduced-form function of t and the equilibrium prices of components A and B , denoted by $p_A(t)$ and $p_B(t)$, respectively. These prices depend explicitly on the realized value of t and implicitly on the realized quality levels of suppliers of component B . The equilibrium prices also depend on the number and ownership of the B -suppliers.

Total differentiation yields the marginal benefit to firm M from increasing t :

$$d\pi/dt = \partial\pi/\partial t + (\partial\pi/\partial p_A)(dp_A/dt) + (\partial\pi/\partial p_B)(dp_B/dt).$$

By the envelope theorem, $\partial\pi/\partial p_A = 0$ and $\partial\pi/\partial t = x$, where x is the equilibrium output level for systems prior to innovation. Hence,

$$d\pi/dt = x + (\partial\pi/\partial p_B)(dp_B/dt) .$$

This expression helps identify the effects of integration and competition on innovation incentives. If firm M is integrated and is the sole supplier of B , then $\partial\pi/\partial p_B = 0$ by the envelope theorem, and $d\pi/dt = x$. If there is a single supplier of B , but that supplier is independent of firm M , then we would expect investment incentives to be lower for two reasons. One, the equilibrium value of x would be lower due to double marginalization. Two, with an independent B -monopolist, $(\partial\pi/\partial p_B)(dp_B/dt) < 0$; $\partial\pi/\partial p_B < 0$ because the sale of component A is harmed, and $dp_B/dt > 0$ because the independent supplier alters its price to appropriate some of the gains from innovation.

Competition in the supply of B can help restore incentives toward the integrated level. When the price of component B is driven by competition (*i.e.*, is set to yield the same quasi-surplus as the second-best variant of B), firm M 's incentives to improve component A increase for two reasons. One, the hedonic price of component B will be lower, raising the equilibrium value of x . Two, $dp_B/dt = 0$; competition prevents the independent supplier of component B from raising its price to appropriate the benefits of an improvement in component A .

VIII. CONCLUSION

We used a simple model to examine the incentives of a monopoly supplier of one component to integrate into the supply of a complementary component. We focused on markets in which there are multiple suppliers of the complementary component—whether or not the monopolist integrates—and in which R&D or other investments have

significant effects on industry performance. Our analysis indicates that such a monopolist may inefficiently integrate in order to put greater competitive pressures on independent suppliers of the complement. Because it gains from an increase in the quasi-surplus offered to consumers of the complement, the integrated firm tends to have incentives to conduct more R&D and price more aggressively than do its non-integrated rivals. These effects can be inefficient, to the extent that they are driven by the pecuniary gains from lower prices in the complement rather than by internalization of real externalities from innovation.

In many ways, the effects on the integrated firm's R&D and pricing incentives are like those in the standard analysis of integration between two firms each having a monopoly in the supply of one of the components. In the bilateral monopoly model, the changes in incentives generally improve efficiency, because the effects internalized are real externalities. In our model, however, the pecuniary effects can dominate. Although price and investment squeezes often improve ex post efficiency by reducing independent suppliers' price-cost margins, they may worsen ex ante efficiency by discouraging independent investment.

We also examined the monopoly supplier's incentives to exclude or assist independent suppliers of the complementary component. In our model the most obvious effect is a general incentive to cooperate and help complementary firms. Nevertheless, we found that under complete information, an integrated firm facing a single independent supplier of the complementary component has no incentive to cooperate with that supplier when innovations are non-drastic (although neither does it have an incentive to exclude that supplier). With drastic innovations, multiple independent component

suppliers, or incomplete information, however, the integrated firm does have incentives to cooperate. Even when integrated, the monopolist in our model treats independent firms more as complementors than as competitors.

Much of our analysis concerned incentives of a monopoly supplier to extract quasi-rents from independent innovators in the supply of the complementary component. An intriguing way to think of some of this is that monopolist plays a role like that of a “public-interest” regulator. The monopolist has some incentives to shape the market for the complementary component efficiently because the firm captures many of the efficiency benefits through its sales of the monopoly component. As with a regulator, however, problems arise because the monopolist has a great deal of power and commitments are difficult to make. Amidst concern lest excessive antitrust zeal bring regulation-style problems to the computer industry, we should not forget that an industry with a single gatekeeper would be “regulated” as well.

Although we formally assumed firm M is a monopolist, the issues we studied arise whenever independent B -firms must make investments that are specific to their complementary relationship to firm M . Relationship-specific investments can arise even when M faces competition in the overall systems market. For example, independent service organizations may have to make specific investments in parts, customer lists, and learning how to repair certain brands of hardware. Of course, imperfect systems competition also introduces several additional issues that merit further study.

Appendix

We first examine the effects of integration between firm M , the sole supplier of component A , and firm N , a sole supplier of component B .³⁰ Given the assumption that consumers value quality changes equally, the market demand for systems can be expressed as $D(h)$, where h is the hedonic price of systems and is equal to the sum of the two component prices minus q . Note that, here, we allow demand to be responsive to price: it turns out that the effects we examine here vanish if demand is perfectly inelastic.

Suppose there is no integration and firm N has set the price of B at p . Firm M can be thought of as choosing h to max $\{h - (p - q)\} D(h)$. The resulting quantity is $x^*(p - q)$, where $x^*(\omega)$ is the quantity that would be set by a monopolist with marginal cost ω facing demand curve D . This in turn defines a “derived” demand curve for firm N ’s pricing decision. Defining $n = p - q$, firm N chooses n to maximize $\{n + q\} x^*(n)$. Its choice of n is thus the profit-maximizing price for a monopolist with marginal cost $-q$ facing the demand curve $x^*(\cdot)$.

Suppose firm N has raised its product quality by Δq through innovation. By the standard comparative statics of monopoly pricing, the fall in $-q$ makes firm N better off and leads it to choose a lower value of n . The fall in n decreases firm M ’s effective marginal costs, in turn both increasing its profits and lowering its choice of h . The fall in h makes consumers better off. Thus, when firm N innovates, both firm M and consumers (as well as firm N) are made better off. These effects can vanish, but cannot be reversed, in extreme cases, notably if demand is perfectly inelastic.

³⁰ This is a departure from our main focus, which is on cases where there is at least one independent supplier even after any integration by M .

If the firms integrate, the incentive to make such an innovation is greater, because the previously external positive effect on M 's profits is now internalized.³¹ Moreover, the remaining externality from innovation—the external effect on consumers—is also positive. Hence, when innovation results in a uniform increase in systems reservation prices, the effects of a merger of firms M and N are as follows: (a) the private incentives for innovation increase; and (b) the increased innovation that results is socially desirable.

The following example demonstrates that integration need not increase the incentives to invest in socially valuable R&D for general consumer responses to quality improvements. We relax the assumption that all consumers equally value increased quality. One third of the consumers have a reservation price equal to 2, while two thirds have a reservation price of 1. If firm N innovates, the reservation price of the consumers with relatively high absolute willingness to pay rises to $2+\Delta q$, where $0 < \Delta q < 1$. The demands of consumers with lower willingness to pay are not affected by the innovation. The cost of innovation is I_0 , where $0 < I_0 < (2/3)\Delta q$, and there are no production costs.

It is straightforward to show that, absent integration (and absent any other similar form of cooperation between the two suppliers), sequential double marginalization leads to an equilibrium price at which only the high-value consumers buy. In this case, it is profitable for firm N to innovate, because $I_0 < (2/3)\Delta q$. With integration, the equilibrium systems price is 1, with or without the innovation. Under the integration equilibrium, the marginal consumer does not value increased quality, and there is no incentive to

³¹ Formally, it is straightforward to establish that the equilibrium quantity for any given q is lower when the firms are not integrated due to double marginalization. Therefore, the value of a cost reduction (equivalently, a uniform increase in quality) is greater when the firms have merged.

innovate. This outcome is inefficient since the gross consumption benefits would rise by more than the cost of the innovation: the inframarginal consumers are still buying and they value the increased quality. The critical feature of this example is that inframarginal customers value quality differently from marginal customers.³²

We next provide two results on pricing in a market subject to double marginalization. These results are useful in identifying when an innovation in a single component in a system is drastic. Let $p^*(\omega)$ denote the profit-maximizing price for a monopolist facing demand curve D with unit cost ω . In other words, $p^*(\omega) = \operatorname{argmax}_p D(p)\{p - \omega\}$. We examine how the price chosen by an “upstream” monopolist (such as a uniquely and drastically successful B firm in our model), knowing that its price will in turn be marked up by the downstream monopolist, compares to a unified single-monopolist choice. In particular, if these prices are the same, then we can say whether or not an efficiency difference is drastic without conditioning on the vertical structure.

Lemma A1 states a sufficient condition under which double marginalization by firm M has no effect on the price chosen by an independent supplier of B :

Lemma A1. *If there exist constants α and β such that $p^*(\omega) = \alpha + \beta\omega$ then $\operatorname{argmax}_p D[p^*(p)]\{p - c\} = \operatorname{argmax}_p D(p)\{p - c\}$.*

Proof: Let $p_0 = \operatorname{argmax}_p D[p^*(p)]\{p - c\}$. Then p_0 satisfies the following first-order condition:

$$D(\alpha + \beta p_0) + \beta D'(\alpha + \beta p_0)\{p_0 - c\} = 0.$$

By the definition of p^* , the following first-order condition must also hold:

³² The distortion in incentives due to the divergence between marginal and average valuations of quality improvements is analyzed in Spence (1975).

$$D(p^*(p_0)) + D'(p^*(p_0))\{p^*(p_0) - p_0\} = 0,$$

or

$$D(\alpha + \beta p_0) + D'(\alpha + \beta p_0)\{\alpha + (\beta-1)p_0\} = 0.$$

Substitution then yields,

$$-D'(\alpha + \beta p_0)\{\alpha + (\beta-1)p_0\} + \beta D'(\alpha + \beta p_0)\{p_0 - c\} = 0,$$

which is satisfied if and only if

$$-\{\alpha + (\beta-1)p_0\} + \beta\{p_0 - c\} = 0.$$

This last equation implies that $p_0 = \alpha + \beta c$. However, by hypothesis, $\alpha + \beta c = \operatorname{argmax}_p D(p)\{p - c\}$. **QED**

Lemma A2. *There exist constants α and β such that $h^*(p) = \alpha + \beta p$ if and only if there exists a constant γ such that $\gamma D'^2 = DD''$.*

Proof: $p^*(\omega) = \operatorname{argmax}_p D(p)\{p - \omega\}$ if and only if the following first-order condition is satisfied:

$$D(p^*(\omega)) + D'(p^*(\omega))\{p^*(\omega) - \omega\} = 0,$$

Total differentiation yields

$$\{2D'(p^*(\omega)) + D''(p^*(\omega))\{p^*(\omega) - \omega\}\}dp^* - D'(p^*(\omega))d\omega = 0,$$

or,

$$dp^*/d\omega = D'/\{2D' + D''(p^* - \omega)\}.$$

By the first-order condition for the optimality of p^* , $(p^* - \omega) = -D/D'$. Using this fact, one obtains

$$dp^*/d\omega = D'/\{2D' - D''D/D'\}.$$

Hence, $dp^*/d\omega \equiv \beta$ if and only if $D'^2 = \beta\{2D'^2 - D''D\}$. **QED**

The following example demonstrates that integration by firm M may induce independent suppliers of component B to shift their pricing strategies upward.

Example A1: Suppose the innovation production function satisfies the conditions of the success-failure model in a situation in which there are two suppliers of B and demand is inelastic. Recall that a firm's R&D succeeds with probability p and yields quality q_0 for its component B . With probability $1-p$ the R&D fails and yields a quality of 0. For simplicity, let $c = 0$.

If the two firms active in the market for B both are independents, each sets its price equal to 0 (cost) if its R&D fails and mixes over the interval $((1-p)q_0, q_0)$ if its project succeeds. Letting $G(\cdot)$ denote the distribution function for this mixed strategy, straightforward calculation shows that on this interval $G(p) = 1 - (1-p)(q_0-p)/(pp)$.

Now suppose instead that firm M is one of the suppliers of component B . Firm M sets its price equal to zero no matter what the outcome of its R&D. Taking this fact into account, the independent firm competing against M sets $p = 0$ if its project fails and $p = q_0$ if it succeeds. Thus, an independent firm's response to firm M 's pricing strategy is to shift its pricing strategy *upward*. One can understand this in terms of elasticity of the expected firm-specific demand curve. Firm M 's more aggressive pricing *lowers* that demand curve facing each independent, but (as we see here) need not make it *more elastic*.

Proof of Lemma 1: Let $Q(\cdot)$ denote the cumulative distribution function, as perceived by M in equilibrium, for the *highest* quasi-surplus offered by independent suppliers of B . (In the complete-information case, $Q(\cdot)$ is degenerate.) Thus, if firm M

offers price p and quality q , its probability of making B sales is $Q(q-p)$.³³ Let $R^*(s)$ denote the maximal profits that can be earned from the sale of A given that consumers purchase units of B yielding quasi-surplus s . Note that R^* is an increasing function. Firm M 's expected profits from components A and B together are

$$\pi(p, q) = Q(q-p) \{R^*(q-p) + x^*(q-p)[p-c]\} + \int_{q-p}^{\infty} R^*(s) dQ(s) .$$

If it sells both components (*i.e.*, if it sells B), firm M will earn total profits $R^*(q-c)$ for any p less than or equal to the *systems* price associated with $R^*(q-c)$ when it has quality q and unit cost c . This is immediate if M prices its B component at c , and follows for other prices because M will adjust the price of component A *pari passu* to offset any change in its price of component B . Hence, firm M 's expected profits from components A and B , if it charges such a price, can be expressed as:

$$\pi(p, q) = Q(q-p) R^*(q-c) + \int_{q-p}^{\infty} R^*(s) dQ(s) .$$

It follows that

$$\begin{aligned} \pi(p, q) - \pi(c, q) &= \{Q(q-p) - Q(q-c)\} R^*(q-c) + \int_{q-p}^{q-c} R^*(s) dQ(s) \\ &= \int_{q-p}^{q-c} \{R^*(s) - R^*(q-c)\} dQ(s) . \end{aligned}$$

Hence, $\text{sign}\{\pi(p, q) - \pi(c, q)\} = -\text{sign}(p-c)$. Therefore, firm M 's expected profits are maximized by setting $p = c$. **QED**

Proof of Lemma 2: The first claim holds because making no sales dominates making sales below cost. To see why the second claim holds, it is useful to introduce additional notation. Let $F_i(\cdot)$ denote firm i 's subjective distribution function for $\max_{j \neq i} q_j$.

³³ This assumes the tie-breaking rule that M wins sales if it offers the same surplus as an independent.

Independent firm i hopes to be best at quality q^b if and only if there exists $q^a < q^b$ such that $F_i(q^a) > 0$.

Let $s_k^*(q)$ denote the equilibrium quasi-surplus offered by firm k when it has quality q . Firm rationality implies that $s_k^*(q) \leq q - c$ for all k and q .³⁴ Hence, for $\varepsilon = q^b - q^a$, setting $s_i^*(q^b) = q^b - c - \varepsilon$ yields expected profits of $\varepsilon F_i(q^a) > 0$. Of course, if firm i prices at cost when $q_i = q^b$, it makes zero expected profits. Therefore, $s_i^*(q^b) < q^b - c$.

QED

We turn now to comparison of integrated and independent suppliers' R&D investment incentives with responsive demand and a general R&D production function. Let $f(q; I)$ denote the density function for the quality a firm's variant of component B conditional on the firm's having invested I in R&D. Let $F(q; I)$ denote the associated cumulative distribution function. Let $u_j(q)$ denote firm j 's expected profits conditional on its variant having quality q taking as given the R&D investment levels of all other firms.

Firm j chooses I to maximize

$$\int_0^\infty u_j(q) f(q; I) dq - I.$$

Making use of integration by parts, firm j 's objective function is equivalent to

$$u_j(\infty) - \int_0^\infty u_j'(q) F(q; I) dq - I,$$

and the resulting marginal incentives to increase I are

$$- \int_0^\infty u_j'(q) [\partial F(q; I) / \partial I] dq - 1. \quad (1)$$

If firm j is the integrated firm M , the marginal benefit of increasing q , $u_M'(q)$, is equal to the probability that no more than one of the $(n-1)$ other firms has quality greater

than or equal to q . If firm j is an independent supplier, labeled N , the marginal benefit of increasing q , $u_N'(q)$, is equal to the probability that no other firm has quality greater than or equal to q . Suppose that firms M and N have each undertaken the same level of R&D investment. Then the difference in their marginal valuations of an increase in q is

$$u_M'(q) - u_N'(q) = \Pr[q_i < q \text{ for all } i \neq M, N][1 - F(q; I)] \geq 0 .$$

Note that the right-hand side of this expression must be strictly positive over a set of positive measure for firm N to have positive investment incentives.

By equation (1), firm M 's marginal incentives to increase R&D are equal to firm N 's incentives plus

$$- \int_0^\infty \{u_M'(q) - u_N'(q)\} \partial F(q; I) / \partial I \, dq .$$

We have just shown that the term in curly brackets is non-negative. The fact that an increase in I improves the distribution of q in the sense of first-order stochastic dominance implies that $\partial F(q; I) / \partial I \leq 0$, with strict inequality for all q such that $0 < F(q; I) < 1$. Therefore, firm M would have greater incentives to increase R&D than would firm N . It follows that there cannot exist a single, positive investment level that simultaneously satisfies the first-order conditions for firms M and N .

The argument above establishes that there exist asymmetric equilibria in which firm M conducts more R&D than does an independent supplier. But it does not prove that there cannot be equilibria in which firm M does strictly less than some or all independent suppliers because an increase in the R&D investment of one supplier reduces the investment incentives of its rivals. There is, however, an important case in which we

³⁴ There exist Nash equilibria in which firms that do not make sales set prices below cost. We rule these out as unreasonable. They would not, for example, survive the

can obtain a definite ranking of investment levels, and we the result can be extended to more general conditions.

Lemma A3: Suppose demand is inelastic and the innovation production function satisfies the conditions of the success-failure model. In equilibrium, firm M conducts more R&D than does any independent supplier.

Proof : Recall that in a success-failure model, each firm's quality is 0 if its R&D is a failure and $q = 1$ if it is a success. Being "second" corresponds to being one of two successful innovators.

Suppose, counterfactually, that an independent B -supplier, firm N , conducts strictly more R&D than firm M , $\rho_N > \rho_M$.³⁵ Let Γ_k denote the probability that k of the firms other than M and N succeed. Firm N 's expected payoff (gross of the R&D costs) is equal to q times the probability that it succeeds and everyone else fails, or $q \rho_N (1 - \rho_M) \Gamma_0$. The optimality of ρ_N for firm N implies that firm N weakly prefers ρ_N to ρ_M :

$$q (1 - \rho_M) \Gamma_0 (\rho_N - \rho_M) \geq I(\rho_N) - I(\rho_M) > 0 . \quad (2)$$

Firm M 's gross expected payoff is equal to q times the probability that it succeeds and no more than one other firm succeeds, or $\rho_M \Gamma_0 + \rho_M (1 - \rho_N) \Gamma_1$. The optimality of ρ_M for firm M implies

$$q \{ \Gamma_0 + (1 - \rho_N) \Gamma_1 \} (\rho_N - \rho_M) \leq I(\rho_N) - I(\rho_M) . \quad (3)$$

$\Gamma_0 > 0$ and $\rho_N \leq 1$. Hence, if either $\rho_M > 0$ or $\Gamma_1 > 0$, inequalities (2) and (3) cannot simultaneously be satisfied. Suppose $\rho_M = 0 = \Gamma_1$. In this case (2) and (3) could

introduction of trembles.

be simultaneously satisfied as equalities. But then firm N would be indifferent between ρ_N and 0, which implies that firm N would earn 0 expected profits in equilibrium. But when (3) holds with equality, the convexity of $I(\cdot)$ implies

$$q \Gamma_0 \rho_N/2 > I(\rho_N)/2 .$$

Thus, choosing $\rho_N/2$ would yield firm N positive expected profits, contradicting the optimality of ρ_N . Therefore, ρ_N cannot be larger than ρ_M .

The previous result established that equilibrium cannot entail $\rho_N = \rho_M > 0$ and the conditions of the success failure model ensure that at least one firm invests in R&D. Therefore, firm M must conduct more R&D in equilibrium than any independent supplier. **QED**

³⁵ The proof assumes that firms M and N play pure strategies. The logic of the proof, however, implies that, if firm M mixes, it does so over pure strategies each of which entails more R&D than does any of the pure strategies over which firm N mixes.

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